APPENDIX A.

Ocean Discharge Criteria Evaluation

for the General NPDES Permit for

Alaskan Seafood Processors:

DRAFT TECHNICAL REPORT

July 8, 1994

EPA invites your review of this technical document. In particular, the Agency seeks information which will improve the quality of the evaluation and make it a more useful resource for the public. Please submit your comments and any supporting documentation to Burney Hill, EPA Region 10, Wastewater Management and Enforcement Branch, at the following EPA address.

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3.0 TRANSPORT, FATE, AND PERSISTENCE OF MATERIALS DISCHARGED

Alaskan seafood processing results in the discharge of wastewater consisting of solid and liquid wastes. These wastes consist primarily of dissolved and particulate organic matter and nutrients. Depending on the type and amount of waste discharged, and the physical, biological, and chemical characteristics of the receiving water, wastewater discharges from seafood processors have the potential to impair designated beneficial uses of the marine waters of Alaska. These potential adverse effects on the quality of marine waters of Alaska include reduction in water column dissolved oxygen due to the decay of particulate and soluble waste organic matter, the release of toxic levels of sulfide and ammonia from decaying waste, nutrient enrichment (eutrophication) and stimulation of phytoplankton growth and alteration of the phytoplankton community, and the accumulation of buoyant waste solids and fish oils on the water surface and shorelines.

Seafood waste discharges also have the potential to accumulate on the receiving water bottom in the vicinity of the discharge. The accumulation and decay of seafood waste solids results in the smothering of benthic marine organisms, and the release of carbon dioxide, methane, ammonia, soluble phosphorus, and hydrogen sulfide. The decay of the waste accumulation and the release of microbial decomposition by-products (e.g., sulfide and methane) also exerts a demand on the dissolved oxygen content of the overlying water column and within the sediments. These potential impacts on marine organisms are discussed in detail in Section 5.0 and the potential for exceedances of Alaska's marine water quality criteria are discussed in Section 9.0.

The following section describes a conceptual model of the transport, fate, and persistence of discharges from seafood processing facilities in Alaska and the potential adverse environmental impacts due to these discharges. The development of a computer model to predict the accumulation, persistence, and areal coverage of discharged seafood solid wastes is also described and the results of model case studies are summarized.

Because a number of Alaskan seafood waste discharges have resulted in the persistence of bottom accumulations of waste (see Section 2.6), and adverse effects on benthic organisms have been observed in the vicinity of the discharge (see Section 5.2), the focus of this section is primarily on the transport, fate, and persistence of seafood waste solids. Because the new NPDES general permit includes the allowance of a persistent (i.e., year-round) bottom accumulation of seafood waste of no more than 0.40 ha (1.0 ac), predicting the bottom area covered by seafood solid waste accumulations and the depth of the deposited solids on the bottom as a function of distance from the discharge point is also of interest.

This section begins with the description of a generalized conceptual model of the significant variables (biological, chemical, and physical) that affect the transport, fate, and persistence of seafood waste discharges (Section 3.1), followed by a description of the development of a computer model to predict the deposition of seafood solid waste and the selection of model input variables and modeling case scenarios (Section 3.2). A summary of the results of twelve modeling case scenarios based on the selected input variables to the computer model is also provided (Section 3.3).

3.1 CONCEPTUAL MODEL OF SEAFOOD WASTE DISCHARGES

The following is a description of a conceptual model of the most important factors that control the fate, transport, and persistence of seafood processing waste discharges, including the potential adverse environmental impacts associated with the discharge of seafood waste. The conceptual model is presented graphically in Figure 3-1.

Seafood wastewater discharges consist of a combination of dissolved and solid waste particles (see Section 2.0). The dissolved portion of the waste consists of water soluble organic compounds and soluble nutrients. The liquid portion of the waste may also contain disinfectants used to clean the processing areas. The solid fraction of the waste should be ground to a particle size of 1.3 cm (0.5 in) diameter or less before discharge. The solid fraction consists of a variety of particles which may range from small bits of bone, shell, fat, or flesh to larger fragments of internal organs and fragments of flesh and fat attached to bone, shell, or connective tissue. Thus the solid fraction likely consists of a range of solid particle sizes with chemical compositions and densities that depend on the relative amount of protein, fat, bone, chitin, and connective tissue in each particle.

Once discharged to the receiving water, the rate at which the liquid and solid wastes are dispersed and advected away from the point of discharge will depend on the physical and chemical properties of the discharged waste discussed above, and the physical oceanographic characteristics of the receiving water. These oceanographic characteristics include the location of the discharge in the water column, the presence or absence of density stratification, water depth and bottom topography, and prevailing directions and speeds of wind- and tidally-forced currents. The solid waste particles will settle to the bottom at a rate that depends on the shape, density, and size of the individual particles. Once deposited on the bottom, periods of high currents or storm wave-induced bottom turbulence can result in the resuspension and transport of deposited seafood waste solids away from the point of discharge.

Following their discharge to the receiving water, the particulate and soluble wastes are subjected to chemical and biological transformations that result in the decomposition of the waste materials and the production of bacteria and chemical compounds. The decomposition of the soluble and particulate organic matter consumes dissolved oxygen and results in the production of varying quantities of soluble compounds including carbon dioxide, methane, ammonia, soluble phosphorus, and hydrogen sulfide. Scavenging organisms including fish, crabs, and polychaete worms may also feed on the particulate waste that is suspended in the water column or fresh waste that has accumulated on the bottom.

The adverse environmental effects associated with the discharge include reduction of water column dissolved oxygen concentrations and reduction of oxygen in sediments affected by decaying waste accumulated on the bottom. Seafood wastes also have the potential to be toxic to marine organisms via the discharge of wastewater containing ammonia and residual chlorine compounds and the bacterially-mediated production of ammonia and hydrogen sulfide from decaying waste accumulations. Direct smothering of benthic organisms may occur due to the accumulation of seafood waste on the bottom. If phytoplankton in the vicinity of the waste discharge are nitrogen or phosphorus limited, the additional nutrients supplied by the waste discharge may increase phytoplankton productivity and alter the species composition of the phytoplankton community.

The available information on the character and quantity of Alaskan seafood processing waste discharges has been summarized in Section 2.0. The most important variables that affect the transport, fate, and persistence of seafood processing wastes subsequent to their discharge to receiving waters are 1) the physical oceanographic characteristics of the receiving water, 2) the distribution and settling velocities of the waste particles, and 3) the loss processes and decay rates of the discharged organic matter. The available information on these variables that is relevant to predicting the transport, fate, and persistence of seafood processing waste discharges to marine waters of Alaska is summarized below.

3.1.1 Physical Oceanographic Characteristics of the Receiving Water

Significant physical oceanographic characteristics to consider include water temperature, density stratification, and water circulation in the vicinity of seafood processing discharges. Significant seasonal variation in water temperature and density structure occur in the Gulf of Alaska and the Bering Sea, especially in coastal waters in the vicinity of large freshwater inputs during winter and spring. Elevated surface water temperatures lower the saturation concentration of dissolved oxygen. Warmer surface waters overlying colder water also results in greater density stratification. Warmer surface waters occur in late summer. Density stratification of the water column can result in the trapping of waste discharges well below the water surface which may result in lowered dilution of the wastewater discharge, but prevent the appearance of the wastewater plume on the water surface.

Water circulation results in the advection or transport of discharged wastewater, and when bottom currents (or wind-induced waves) are strong enough, solid wastes that have settled on the bottom may be resuspended and transported away from the discharge. Water circulation occurs through wind- and tidally-driven currents. The amount of wind- and tidally-induced circulation will vary seasonally, and tidally-induced currents will vary over the course of the day in many coastal areas of Alaska which experience semidiurnal tides. Wind-driven circulation most strongly influences circulation patterns during winter storms that frequent the Gulf of Alaska and Bering Sea.

Although it would be difficult to classify the marine waters of Alaska into regionally distinct oceanographic regimes, some generalizations can be made from the available data on tide ranges and maximum tidal currents (Table 3-1). Tide ranges and hence tidal currents are generally highest in the areas of Southeast Alaska, Prince William Sound, Cook Inlet, and Bristol Bay. Diurnal tides range between 3.1 and 8.8 m (10.1-28.8 ft) at Yakutat and Anchorage, respectively. Maximum tidal current speeds in these areas range from 0.05 to 1.8 m/sec (0.1-3.5 kn) at Juneau and Anchorage, respectively. The highest tide ranges and tidal currents occur in Cook Inlet, an estuary with one of the greatest tidal amplitudes and currents known.

In the area of the Alaska Peninsula and Aleutian Islands, including the Pribilof Islands and the island of Kodiak, and in the northern portion of the Bering Sea in the vicinity of Kuskokwim Bay, and Norton and Kotzebue Sound, the tide range and tidal currents are generally lower. Diurnal tides in these areas range between 0.5 and 3.3 m (2.9-10.8 ft) at Nome and Port Moller, respectively. The predicted maximum tidal current speed at Port Moller is 0.97 m/sec (1.9 kn).

It should be noted that seafood processing operations that occur at a fixed position (i.e., shore-based and anchored floating processors) generally choose to operate in locations that are relatively protected so that fishing and supply vessels can easily dock and transfer catch or load finished products. The locations of seafood processing operations in Alaska can be generally represented by four physical oceanographic environments.

- Protected bays or harbors with reduced wave action, but possibly significant tidal currents.
- Nearshore open coastal areas which are affected by wave action depending on the water depth and wind- and tidally-driven currents.
- Rivers or estuary mouths with some wave action and a predominant tidal and freshwater influence.
- Open water which is affected primarily by wind-driven currents, although tidal currents may be important at some locations.

Because stationary operations are typically located in coastal environments with reduced currents and wave action, discharges from these facilities are most likely to result in the accumulation of solid waste on the bottom in the vicinity of the discharge.

3.1.2 Seafood Waste Particle Settling and Resuspension Current Speeds

Seafood waste particle settling velocities and the current speeds required to resuspend deposited waste particles are important factors that affect the fate, transport, and persistence of the seafood waste solids that are discharged. Estimates of these variables for seafood waste solids are summarized below.

3.1.2.1 Settling Velocities of Seafood Waste Particles. Ground seafood waste that is discharged are required to consist of solid particles that are no larger than 1.3 cm (0.5 in) in any dimension. Currently, no studies have been identified that have adequately characterized the particle size distribution of ground seafood waste or the characteristic settling velocities of these particles. However, one study of the open-water disposal of ground seafood waste conducted in Chiniak Bay, Kodiak Island, Alaska, provides a first-approximation of the settling velocities of seafood waste particles (Stevens and Haaga 1994). Unground particles (primarily gills, skin, fins, and viscera 5-25 cm in diameter) required approximately 0.5 hr to settle to the bottom at depths of 120 to 150 m (394-492 ft) (Stevens and Haaga 1994). Smaller particles (less than 1 cm diameter) required more than 1 hr to settle to the bottom. These ranges in settling times and water depths provide approximate bounds for the settling speeds of typical seafood waste particles of 0.03 to 0.08 m/sec (0.098-0.262 ft/sec).

An approximation of the settling velocities of seafood waste particles can also be predicted using the method described by Sleath (1984). This method calculates the settling velocity of a smooth, non-rotating spherical particle of a specific diameter and density in a motionless fluid. The density of a seafood waste particle can be approximated assuming a density of 1.0, 1.5, 0.9, and 3.0 for water, protein, fat/carbohydrate, and bone/chitin, respectively, and a percent water, protein, fat/carbohydrate, bone/chitin content of 75, 15, 7, and 3, respectively (see Table 2-10). These assumptions result in an estimated particle density of 1.13 g/m^3. The calculated settling velocities of spherical particles with diameters ranging from 0.1-1.3 cm (0.04-0.51 in) and a density of 1.13 g/m^3 are shown in Table 3-2.

These predicted settling velocities are generally much greater than those suggested by the observations of Stevens and Haaga (1994) described above. A spherical particle density that would result in settling velocities that were more consistent with the observations of Stevens and Haaga (1994) is 1.05 g/m^3 (see Table 3-2). The differences between the predicted and observed settling velocities may be due to 1) differences in particle sizes (the particle size distribution observed by Stevens and Haaga may have been biased to larger particles), 2) overestimation of actual settling velocities for a given particle density using the method described in Sleath (1984) due to non-spherical particle shapes and greater drag forces of the actual particles, or 3) overestimation of the actual particle densities. The method described by Sleath (1984) has been developed for idealized particles and has been applied most successfully to predicting the settling velocities of fine mineral particles with relatively small diameters. This method may not be as reliable for the prediction of the settling velocities of relatively large, irregularly shaped organic waste particles.

3.1.2.2 Resuspension Current Speeds. The settling velocity of the solid waste particles (and the height of the discharge above the bottom) affects the initial areal extent of the deposit of solid waste on the bottom in the vicinity of the discharge. However, in regions which experience high currents it is important to consider the potential for the solid waste particles to be resuspended following deposition. If solid waste is resuspended and transported away from the vicinity of the discharge, the accumulation of solid waste would be less than that predicted based on the settling velocity and decay rate of the waste solids. The potential adverse impacts to benthic communities would also be reduced.

Resuspension and transport of deposited seafood waste solids is possible if the current speeds are sufficiently large. Periodically high current speeds can result due to wind, tide, or wave action along the coast. Along the coast of Alaska, the currents in many areas are dominated by semidiurnal tidal currents. These can be approximately represented as a sine wave with amplitude equal to the maximum current speed. Assuming that the maximum current speed exceeds the critical resuspension current speed required to lift waste particles off the bottom, then resuspension and transport of material is possible during a portion of a tidal cycle. The amount of material transported depends on the duration and frequency of occurrence of the critical current speed. The critical current speed depends on the size and density of the waste particles, and the cohesiveness of the waste accumulation on the bottom.

The critical resuspension current speed [i.e., the critical current speed 1.0 m (3.3 ft) above the seafloor (U_{100})] can be estimated for a particle of specified diameter and density in a non-cohesive sediment using Shield's diagram (Vanoni 1977) to compute the critical shear velocity u_* and the relation $u_* = (0.003)^{0.5} * U_{100}$ (Sternberg 1972). Critical resuspension current speeds calculated using this method are shown in Table 3-2 for the same particle sizes and diameters used to estimate settling velocities. These current speeds are necessarily first-approximations because the critical resuspension current velocities predicted using this method do not incorporate the effect of the cohesiveness of the waste solids accumulation which will necessarily resist resuspension and transport (Nowell et al. 1981). Diver observations of seafood waste piles have often noted a microbial mat over the surface of the pile which may increase the resistance to resuspension of decaying waste (e.g., U.S. EPA 1991). The actual critical resuspension current speeds are therefore likely to be higher than those shown in Table 3-2.

Although resuspension current speeds are likely to be higher near the bottom in shallow water than in deeper water, it should not be concluded that it would be more advantageous to locate seafood waste discharges in shallow waters. Shallow wastewater discharges will result in relatively lower initial dilution of the soluble portion of the waste due to the limited volume of dilution water available in shallow areas. Discharges in shallow nearshore waters also increases the potential for the surfacing of the waste plume and the accumulation of solids along the shoreline in the vicinity of the outfall.

3.1.3 Seafood Waste Decay and Loss Processes

Waste solid and liquid (i.e., particulate and dissolved) organic matter is decomposed by bacteria and eaten by scavenger organisms when released into the environment. The rate of decomposition or decay not only determines the persistence of the released organic matter, but the decay also results in the consumption of oxygen and the release of soluble compounds including nitrogen (e.g., ammonia), phosphorus (as soluble phosphorus), carbon dioxide, hydrogen sulfide, and methane.

Microorganisms mediate the chemical oxidation responsible for the degradation of organic matter. Microorganisms require an electron acceptor to accomplish this reaction, and different electron acceptors yield different amounts of usable energy. In the environment, the degradation of organic matter involves a series of reactions, each successive reaction yielding less energy per unit of carbon oxidized than the previous reaction. Simplified forms of these reactions are presented in Table 3-3. It is also important to note that the stoichiometry of organic matter, here formulated as $(CH_2O)_x(NH_3)_y(HPO_4)_z$, is much more complex than represented. The organic matter is actually composed of various complex chemicals that may be generally grouped as proteins (amino acids) and soluble material (which contain nitrogen, phosphorus, and sulfur), fats and carbohydrates, and proteinaceous mineral matter that comprises skeletal and connective tissue (e.g., chitin which also contains nitrogen) (see Section 2.6.1).

A more detailed organic matter composition can be approximated to better describe the amount of nitrogen, phosphorus, and sulfur that is liberated during the organic matter microbial decay process. The relative amount of these elements varies among the various types of organic matter. For example, Vollenweider (1985) described the theoretical stoichiometry of protein, lipid, and chitin with the following chemical formulas:

- Protein and soluble material: $C_{61}N_{16}H_{100}O_{24}SP$[1]

- Chitin and connective tissue: $C_{32}N_4H_{56}O_{20}$

- Fats and carbohydrates: $C_{15}H_{30}O$.

All of the sulfur and phosphorus and most of the nitrogen is contained in the protein and soluble fraction of the organic matter.

The rate of decay of organic matter depends on several factors including the composition of the material (i.e., refractory or labile) and decomposition pathways which depend on the chemical (e.g., oxic vs. anoxic) and physical (e.g., temperature and currents) environment. Values of organic matter decay rate constants reported in the literature are extremely variable (see Table 3-4), ranging over five orders of magnitude (1.6×10^{-6} to 1.4×10^{-1} day^{-1}).

Only one study of the decomposition of discharged seafood waste solids has been identified. In this study Tetra Tech (1986,1987) developed and calibrated a seafood waste pile decay model to predict the accumulation and decay of solid seafood waste disposed in Akutan Harbor, Alaska. The model assumed that: 1) all of the waste discharged accumulated at the point of discharge (i.e., no losses due to resuspension or slumping and transport) and 2) the decay of the pile was due only to microbial activity (i.e., scavenging by organism was not an important loss process). Decay rates were developed for the aerobic and anaerobic decay of fish and crab composed of protein, fats and carbohydrates, and bone or chitin. The first-order decay rate constants that provided a reasonable fit to the available data on the temporal variability of the waste pile volumes were 0.1, 0.01, and 0.001/day for aerobic decay and 0.01, 0.005, and 0.0005/day for anaerobic decay of protein, fats and carbohydrates, and bone/chitin, respectively (Tetra Tech 1986,1987).

The activity of scavenging organisms may also account for the reduction in the volume of accumulated waste in the vicinity of the discharge. However, no quantitative information regarding the consumption

[1]The elements of the chemical formula are designated by the following symbols: C = carbon, N = nitrogen, H = hydrogen, O = oxygen, S = sulfur, and P = phosphorus.

(i.e., loss) rate of seafood waste by organisms has been identified. However, marine organisms such as fish and invertebrates have been observed to feed on recently discharged solid waste particles (Hill, B., 8 June 1994, personal communication; Stevens and Haaga 1994). No quantitative studies regarding the importance of this activity have been identified.

The microbial decomposition process results in the liberation of a number of soluble compounds depending on the supply of electron acceptors (e.g., oxygen, nitrate, and sulfate) and the oxidation-reduction state of the environment and the amount liberated depends at least partly on the rate of decay of the organic matter (Froelich et al. 1979; Aller 1982). The microbially mediated reactions typically proceed in a predictable sequence based on the amount of energy released from the reaction beginning with the aerobic decomposition of in the presence of oxygen, nitrate reduction of organic matter using nitrate as an electron acceptor and iron and manganese reduction in the near absence of oxygen, and sulfate reduction, methane production, and fermentation in the absence of oxygen (see Table 3-3). All of the microbial decay processes result in the liberation of soluble phosphate. Additional biological and chemical reactions can result in the assimilation of the released phosphate or the binding of phosphate to mineral particles. However, several studies have found that the amount of phosphorus actually released is typically greater than that predicted using stochiometric models due to the release of mineral-derived phosphates bound to sediments under the near anaerobic conditions typical of organic rich sediments (e.g., Almgren et al. 1975; Froelich et al. 1979). Nitrate and ammonia nitrogen compounds are also released from decaying organic matter, but additional microbial reactions such as assimilation and the transformation of ammonia to nitrate (i.e., nitrification), and nitrate to nitrogen (i.e., denitrification) serve to reduce the amount of ammonia and nitrate release to the overlying water column. The underestimation of the amount of nitrogen compounds released during organic matter decay using stochiometric models has been attributed to the loss of these compounds via nitrification-denitrification (e.g., Almgren et al. 1975). Hydrogen sulfide is also produced from the reduction of sulfate during anaerobic decay of organic matter in the presence of sulfate. However, additional chemical reactions complicate the prediction of the amount of sulfide released from decaying organic matter using simple stochiometric models. These reactions include the rapid oxidation of sulfide (Almgren and Hagström 1974) and the binding of sulfide with mineral particles.

3.2 DEVELOPMENT OF A NUMERICAL MODEL TO PREDICT DEPOSITION OF SEAFOOD WASTE

Due to the diversity of Alaskan seafood processing operations and the variety of physical oceanographic conditions, a computer model of seafood processing waste discharges would provide a very useful tool to evaluate the transport, fate, and persistence of discharged seafood waste. The ideal computer model would simulate all of the relevant physical, chemical, and biological processes and provide predictions for all potential adverse impacts on marine and coastal communities including effects on fish, marine birds, and humans. However, due to limitations in the understanding of physical and chemical processes, interactions between chemical and physical processes and biological communities, and limitations in computing power, computer models are typically mathematical simplifications of the most relevant processes and interactions (Thomann and Mueller 1987, p. *x*). The following sections describe the selection and development of a computer model with the capabilities to predict the long-term accumulation of solid waste on the bottom in the vicinity of seafood processors discharging from a fixed location.

The new NPDES general permit classifies Alaskan seafood processing operations into three categories.

- *Offshore floating seafood processors*—operating and discharging more than one (1) nautical mile (1.9 km) from shore at MLLW.

- *Nearshore floating seafood processors*—operating and discharging from one (1) to one-half (0.5) nautical mile (1.9-0.9 km) from shore at MLLW.

- *Shore-based seafood processors*—operating and discharging less than one-half (0.5) nautical mile (0.9 km) from shore at MLLW.

It is predicted that significant accumulations of seafood solid waste will only occur in the vicinity of *nearshore floating* and *shore-based* seafood processing operations that discharge at a single fixed location. *Offshore* floating processors are not expected to remain in a single location, and therefore the solid wastes discharged by these facilities will be dispersed and will not result in a persistent accumulation of solid waste on the bottom. A study of the disposal of seafood solid wastes in the offshore waters of Chiniak Bay, Alaska, indicated the rapid disappearance of bottom deposits of seafood waste (Stevens and Haaga

1994). Therefore, the modeling effort focused on the prediction of solid waste accumulations in the vicinity of *nearshore* and *shore-based* facilities that discharge from a single fixed location.

3.2.1 Model Selection

Two EPA-supported computer models were initially identified that could effectively model the deposition, decay, accumulation, and areal extent of seafood solid waste. The two EPA models identified were the Simplified Deposition Calculation (DECAL) (U.S. EPA 1987) and the Water Quality Analysis Program Version 5.10 (WASP5) (Ambrose et al. 1988). Both models were considered suitable for modeling the deposition, decay, and accumulation of seafood solid waste. However, WASP5 is also capable of modeling water column dissolved oxygen and nutrient-phytoplankton interactions. These additional capabilities of WASP5 as well as the potential to incorporate the influence of relatively complex shorelines and tidally-varying current speeds and directions resulted in the selection of the WASP5 model for use in predicting the areal extent of seafood waste solids accumulation. However, the additional complexity of the WASP5 model results in some sacrifice in ease of use and increases the amount of computing time required to run the model. The original WASP5 computer code also required some modifications to accommodate the prediction of organic solids decay and accumulation.

3.2.2 Description of the Modified WASP5 Model

The existing WASP5 and EUTRO5 (a sub-model component of WASP5) models (version 5.10) were modified by adding three state variables to represent three size classes of seafood waste solids particles. The proportion of solids in each of the three size classes and their settling velocities can be specified in the model. Seafood waste solids are modeled on a dry weight basis with decomposition accounted for in the oxygen balance through a 50 percent carbon:dry weight ratio and a stoichiometric factor of 2.67 g O_2/g C. Additional secondary output variables were added to the EUTRO5 sub-model to track the dry weight deposition flux of each size class of seafood waste as it passed from the water column to the bottom sediments. Also, additional kinetic constants were added to the EUTRO5 sub-model to account for the carbon:dry weight ratio and the first-order decomposition rates in the water column and sediment layers.

The current model uses a simple scheme of a steady along-shore net-drift current speed. This is the long-term net transport rate away from the point of discharge. Longitudinal, lateral, and vertical dispersion coefficients are used to approximate the spreading of the waste due to tidal actions. As currently modified, the model does not account for resuspension and transport of deposited waste solids. The potential for resuspension and transport can be assessed using estimates of the resuspension current speeds necessary to transport deposited solid wastes, and site specific information regarding average maximum current speeds, peak current speeds, and their duration.

The modeling grid system consists of a variably-spaced Cartesian grid system with two water column layers and one benthic layer. In the vicinity of the discharge there are 25 small segments each having a dimension of 18x18 m (59x59 ft) which provides a 0.81 ha (2.0 ac) coverage of fine resolution computational cells (see Figure 3-2). As one moves away from the discharge, the segment sizes become progressively larger. The entire grid system consists of 300 water column segments and 150 benthic segments.

Because WASP5 does not explicitly model the initial dynamics of the buoyant wastewater plume, the waste discharge point source is located between the upper and lower water layers that are simulated in the model. The effect of density stratification on mixing and dilution of the wastewater plume is not considered in the model..

The current version of the model provides predictions of the areal extent and the depth of the seafood waste deposit depending primarily on the horizontal dispersion coefficients, mass emission rate of seafood waste solids (in dry weight), the settling velocities and proportions of solids in each of the three particle classes, the first-order decay rate of waste solids, and the net-drift current speed.

3.2.3 Selection of Modeling Case Scenarios

Twelve modeling case scenarios were developed for application of the WASP5 model to assess the potential for accumulation of seafood solid waste under a variety of conditions (Table 3-5). These scenarios included six simulations for discharges from shore-based facilities with discharges located 2.0 m (6.6 ft) above the bottom in 15.2 m (50 ft) of water. Combinations of low and medium net-drift current speeds [5 and 15 cm/sec (0.10 and 0.29 kn)] and three bottom slopes (0.0, 12.5, and 25 percent) resulted in the six case scenarios modeled for shore-based discharges. These scenarios were selected to evaluate the effect of varying slope and current velocities on the model-predicted accumulation of seafood waste solids from shore-based facilities.

Six case scenarios were also selected to evaluate the effect of varying current speed and water depth on the model-predicted accumulation of seafood waste solids due to surface discharges from stationary floating processors. These simulations included a discharge 2.0 m (6.6 ft) below the water surface in water depths of 15.2, 30.5, and 45.7 m (50, 100, and 150 ft) and a low and medium current speed. The bottom slope in all of these cases was 0.0 percent (i.e., a flat bottom).

For each modeling case scenario, the model was run for varying steady mass emission rates to determine the waste solids mass emission rate that would result in the bottom accumulation 1.0-cm (0.39-in) deep or more over a 0.40 ha (1.0 ac) area at steady-state (i.e., decay losses balanced by waste inputs). Although the WASP5 model has the capability to model time-varying solids mass emission rates, a steady (e.g., annual average) mass emission rate was used to simplify the estimation of the steady-state accumulation of waste solids.

3.2.4 Selection of Model Input Variables

Based on the information provided in Section 2.0 on the characteristics and quantity of Alaskan seafood waste and additional information provided above in Section 3.1, the values for several model input variables were selected for use in the modeling case scenarios. These values were considered to be reasonable estimates for a typical seafood processing waste discharge and receiving water characteristics. Because of the limited information for a number of the model variables (e.g., the first-order organic matter decay rate constant), the selection of input values for these variables was necessarily based somewhat on professional judgement. Due to the relative uncertainty of the values selected, the results of the modeling case scenarios should be considered a first-approximation. However, the modeling case scenarios do provide an indication of the relative sensitivity of the model to the factors that are varied in each case. Sensitivity of the model to particular variables will suggest which variables should be the focus of future laboratory or field investigations.

Table 3-6 shows the variables that were selected for use in the modeling case scenarios. The rationale for the selection of the values for the proportion of solids in the three size classes and their settling velocities and the first-order waste solids decay rate constant is described below.

3.2.4.1 Solids Distribution and Settling Velocities. The settling velocities of the three particle classes were selected from Table 3-2 and were chosen to approximate the range of settling velocities observed by Stevens and Haaga (1994). For lack of better information the distribution of solids in each of the three particle classes was selected as follows. Sixty percent of the waste solids was assumed to be composed of particles with settling velocities of 0.085 m/sec (0.28 ft/sec). Conceptually these are the waste particles with a diameter of 1.3 cm (0.5 in). Twenty percent of the waste solids were assumed to be composed of particles with settling velocities of 0.045 m/sec (0.15 ft/sec). Conceptually these are particles with a diameter of 0.635 cm (0.25 in). Twenty percent of the waste solids were assumed to be composed of particles with settling velocities of 0.022 m/sec (0.072 ft/sec). Conceptually these are particles with a diameter of 0.318 cm (0.125 in).

3.2.4.2 Waste Solids Decay Rate Constant. Because of the wide range of possible organic matter decay rates, and because of the uncertainty regarding the significance of scavenging of the waste by organisms, the model waste solids decay rate constant was estimated by holding all model variables constant (the low current speed case was used) and comparing the model results to an actual Alaskan seafood waste discharge with a known annual discharge rate and a reasonably well surveyed waste accumulation in the vicinity of the discharge. It was assumed (although no data were available to verify the assumption) that the actual waste accumulation was not affected by resuspension and transport of the waste that had been deposited. The areal extent of the waste accumulation predicted by the model was compared to the observed areal extent of the actual waste accumulation. The model decay rate constant was adjusted until a reasonable agreement was obtained between the bottom coverage predicted by the model and the observed waste coverage.

This comparison process resulted in the estimation of a first-order waste decay rate constant of 0.02 day^{-1} which is within the range of values presented in Table 3-4.

If field data had been available for the net-drift current speed, waste solids particle distribution, and particle settling velocities for the actual discharge studied, the decay rate could have been estimated more precisely. Nonetheless, the method used to estimate the decay rate likely provided a reasonable estimate of a decay rate constant that has been shown to vary over five orders of magnitude depending on the environment and type of organic matter (see Table 3-4).

3.3 MODELING CASE SCENARIO RESULTS

The WASP5 seafood waste accumulation model was run iteratively to predict the steady-state solid waste discharge rate that would produce a bottom accumulation of seafood waste with a depth of 1 cm or greater over an area of 0.40 ha (1.0 ac) (Table 3-7). These results provide a first-approximation of the annual seafood solid waste discharge rate that would result in a bottom accumulation of seafood waste equal or exceeding the proposed zone-of-deposit of 0.40 ha (1.0 ac). This iterative process was conducted for each of the twelve case scenarios. The model predictions are based on the assumption that resuspension and transport is negligible. Resuspension and transport of deposited solids may occur at individual facilities if bottom current speeds exceed the critical current speed required to resuspend bottom waste accumulations (see Section 3.1.2.2). Therefore, the model predictions may be considered conservative estimates of the potential for waste accumulation under the conditions described in the model for the twelve case scenarios. The results for the near-bottom shore-based and near-surface floating discharges are summarized and discussed below.

Two estimates of the areal extent of the waste pile have been provided in Table 3-7. The first areal coverage estimate is based on interpolation of the WASP5 model-estimated waste deposit depths in each modeling cell using the computer program SURFER™. This program creates contour plots of the depth of the waste pile based on the model-estimated waste deposit depths in each WASP5 modeling cell and calculates the area covered by waste deposits 1 cm deep or greater (Figure 3-3). The second estimate of the areal extent of the waste pile is based on summing the areas of the WASP5 modeling cells that contain accumulations of seafood waste solids 1 cm deep or greater. For example, if the waste accumulation was greater than 1 cm in all of the smallest WASP5 modeling cells near the discharge point [i.e., 9, each with an area of 0.03 ha (0.08 ac)] in the vicinity of the discharge, then the estimated areal coverage of seafood waste solids greater than 1 cm deep would be 0.27 ha (0.72 ac). For the near-bottom shore-based and near-surface modeling case scenarios the two estimates are similar, generally within 20 percent.

3.3.1 Near-Bottom Shore-Based Discharges

The first-approximation of the annual near-bottom shore-based seafood waste solids discharge that would result in a waste accumulation greater than 0.40 ha (1.0 ac) in waters with a net-drift current speed of 5.0 cm/sec (0.16 ft/sec), a depth of 15.2 m (50 ft), and a flat bottom is 16 million pounds (wet weight) of waste solids. The maximum accumulated solids depth of this pile is predicted to be 230 cm (7.5 ft). The first-approximation of the amount of seafood waste solids discharge that would result in the accumulation of greater than 0.40 ha (1.0 ac) of seafood waste on the bottom in waters with a net-drift current speed of 15.0 cm/sec (0.49 ft/sec), a depth of 15.2 m (50 ft), and a flat bottom is 12 million pounds of waste solids. The maximum accumulated solids depth of this pile is predicted to be 133 cm (4.4 ft). The first-approximation of the amount of seafood waste solids discharge that would result in the accumulation of greater than 0.40 ha (1.0 ac) of seafood waste on the bottom in waters with a net-drift current speed of 5.0 cm/sec (0.16 ft/sec), a depth of 15.2 m (50 ft), and a sloping bottom (12.5% and 25%) is 20 million pounds of waste solids (see Cases 3 and 5, Table 3-7). The maximum accumulated solids depth of these piles are predicted to be 230 and 288 cm (7.5 and 9.4 ft, respectively). The first-approximation of the amount of seafood waste solids discharge that would result in the accumulation of greater than 0.40 ha (1.0 ac) of seafood waste on the bottom in waters with a net-drift current speed of 15.0 cm/sec (0.49 ft/sec), a depth of 15.2 m (50 ft), and a sloping bottom (12.5% and 25%) is between 12 and 16 million pounds of waste solids (see Cases 4 and 6, Table 3-7). The maximum accumulated solids depth of these piles are predicted to be 179 cm (5.9 ft).

The model predicts that less waste discharge is required to create a 0.40 ha (1.0 ac) pile 1 cm deep or greater when the current speed is higher because the higher current speed serves to spread the waste over a larger area. The model predicts that the waste accumulation will be relatively deep [i.e., greater than 1 m (3.3 ft)] because the simulated discharge is 2 m (6.6 ft) above the sea floor and the waste particles settle rapidly to the bottom in the vicinity of the discharge. The model also predicts that on sloping bottoms, more seafood waste can be discharged than on a flat bottom before a pile greater that 0.40 ha (1.0 ac) is created.

The model-predicted estimates of the near-bottom shore-based waste discharges that would result in a 0.40 ha (1.0 ac) waste pile are consistent with the limited data on actual waste pile accumulations in the vicinity of several shore-based seafood processing facilities. The maximum areal extent of waste pile deposits summarized in Section 2.6, 0.3 ha (0.7 ac), was associated with a 1993 annual solids discharge rate of approximately 11.1 million pounds of seafood waste.

3.3.2 Near-Surface Floating Discharges in Open Ocean

The first-approximation of the annual near-surface open water seafood waste solids discharge that would result in a waste accumulation greater than 0.40 ha (1.0 ac) in waters with a net-drift current speed of 5.0 cm/sec (0.16 ft/sec), a depth of 15.2 m (50 ft), and a flat bottom is 8 million pounds (wet weight) of waste solids. The maximum accumulated solids depth of this pile is predicted to be 63.4 cm (2.1 ft). The first-approximation of the amount of seafood waste solids discharge that would result in the accumulation of greater than 0.40 ha (1.0 ac) of seafood waste on the bottom in waters with a net-drift current speed of 15.0 cm/sec (0.49 ft/sec), a depth of 15.2 m (50 ft), and a flat bottom is 4 million pounds of waste solids. The maximum accumulated solids depth of this pile is predicted to be 19.2 cm (2.1 ft). The first-approximation of the annual near-surface open water seafood waste solids discharge that would result in a waste accumulation greater than 0.40 ha (1.0 ac) in waters with a net-drift current speed of 5.0 or 15.0 cm/sec (0.16 or 0.49 ft/sec), depths of 30.5 or 45.7 m (100 or 150 ft), and a flat bottom is approximately 4 million pounds (wet weight) or less of waste solids. The maximum accumulated solids depth of these piles are predicted to be 8-24 cm (0.3-0.8 ft).

The model predicts that discharges to near-surface waters will result in areal coverage of 0.40 ha (1.0 ac) of the bottom with significantly less seafood waste discharged than the near-bottom discharge model cases. These results can be explained by the fact that seafood waste discharges to the near-surface waters are exposed to the currents during settling for a longer time than the near-bottom discharges, and consequently, are dispersed over a larger area. As can be seen from the predictions of the maximum waste accumulation depths, the volume of material that accounts for the 0.40 ha (1.0 ac) coverage is much less than for the near-bottom discharges (see Table 3-7).

3.3.3 Modeling Case Scenarios Summary

The modeling results suggest the complexity of the regulation of seafood waste discharges. Tradeoffs are evident between the desire to minimize the appearance of wastewater and waste solids at the water surface, the transport of the waste onshore, and the accumulation of waste solids on the bottom, while also trying to maximize the dispersion and dilution of the waste. For shore-based facilities, the seafood waste accumulation model predicts that relatively deep [greater than 1 m (3.3 ft)] waste deposits will occur when the end of the discharge pipe is 2 m (6.6 ft) above the bottom. Increasing the net-drift current speed to 15.0 cm/sec (0.49 ft/sec) spreads the waste over a larger area, increasing the areal coverage of the waste pile. At these current speeds the areal extent of the bottom waste accumulation appears to be controlled primarily by the current speed and not by the amount of the waste discharged. At higher current speeds greater areal coverage of the waste is predicted. On the other hand, the WASP5 seafood waste accumulation model of near-surface discharges from floating facilities predicts relatively shallow deposits [approximately 8-24 cm (0.3-0.8 ft) deep] for the low and medium (5 and 15 cm/sec, respectively) current speeds modeled. Under these conditions the areal extent of the waste pile greater than 1 cm (0.4 in) deep is controlled primarily by the discharge rate. Greater areal coverage of the waste from near-surface discharges is predicted for lower discharge rates than from near-bottom discharges (see Table 3-7).

The model predictions discussed above are considered conservative estimates of bottom waste accumulation because the WASP5 model does not consider the resuspension and transport of deposited wastes. Therefore, actual bottom accumulations at facilities where current speeds sufficient to resuspend and transport significant amounts of deposited wastes will tend to be much less than those predicted by the model. A first-approximation of the likelihood that resuspension and transport of deposited seafood wastes may occur can be made by estimating or measuring current speeds in the vicinity of individual facilities and comparing them to the estimated resuspension current speeds in Table 3-2.

3.4 SUMMARY

A conceptual model of the fate, transport, and persistence of seafood processing waste was developed that also identified the potential adverse biological effects caused by this discharge. A number of biological, chemical, and physical factors control the fate of the discharged wastes. Biological factors include microbial decay and scavenging of the waste by organisms. Chemical factors include the chemical composition of the waste, particularly the content of protein and soluble organic compounds, fats and carbohydrates, and skeletal and connective tissue. Each of these components has a characteristic chemical composition and decay rate. Physical factors that control the fate, transport, and persistence of the waste include density stratification, storm-, tidal-, and wind-induced currents, and water temperature. Current speed direction and duration strongly influences the transport and dispersion of the waste and critical current speeds can resuspend and transport waste solids deposited on the bottom. Although simple stoichiometric models of organic matter decay have been used by some researchers to predict the release of soluble compounds to the overlying water due to the microbial decay of organic matter, there are a complex of coupled reactions that complicate the reliability of these simple model predictions. These models typically under- predict the amount of soluble phosphorus released, due to the additional release of mineral-bound phosphorus, and these models over-predict the release of ammonia nitrogen and hydrogen sulfide because of additional microbial processes and chemical reactions that reduce the concentrations of these compounds in the overlying water.

A mathematical model was developed to simulate the discharge and accumulation of solid wastes from discharges near the bottom from shore-based facilities, and discharges near the surface from floating processing facilities in open water. Two current speeds (5 and 15 cm/sec) were simulated. For the simulations of shore-based facilities the bottom slope was varied resulting in six case scenarios, and for the floating facilities the water depth was varied which also resulted in six case scenarios. The model was used to provide a first-approximation of the amount of waste solids discharge that would result in an approximately 0.40 ha (1.0 ac) bottom deposit of seafood waste. The modeling results indicated that a steady annual discharge from a shore-based facility of approximately 12-20 million pounds (wet weight) of solid waste would be required to produce a 0.40 ha (1.0 ac) deposit in the absence of significant resuspension and transport of the deposited waste. For a near-surface discharge in 15.2-m (50 ft) water depth a steady annual discharge of approximately 8 million pounds would be required to produce a 0.40 ha (1.0 ac) deposit. In water depths greater than 15.2 m (50 ft), seafood waste discharges of 4 million pounds or less are predicted to create waste deposits of 0.40 ha (1.0 ac).

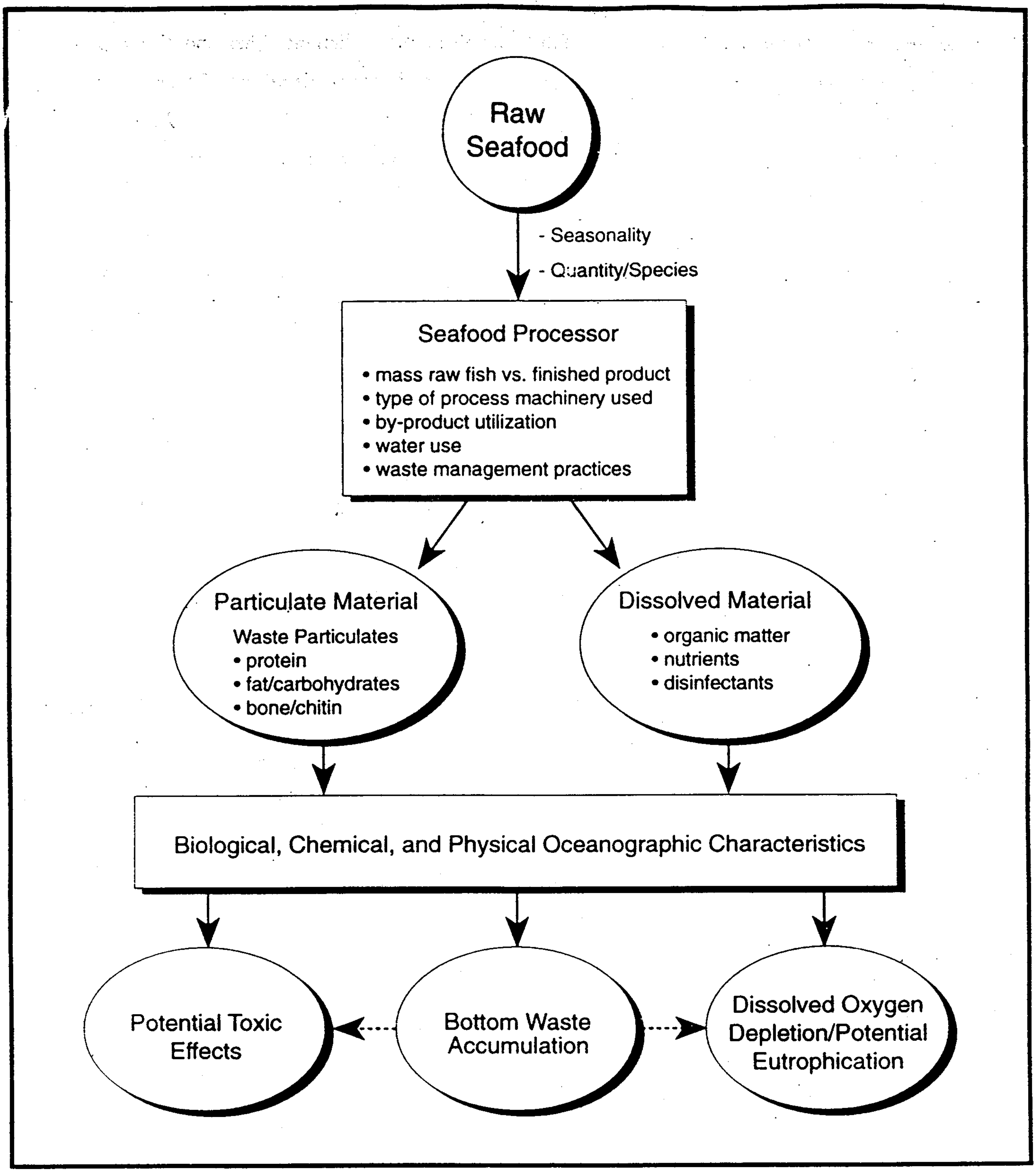

Figure 3-1. Conceptual Model of the Fate, Transport, Persistence, and Potential Adverse Impacts from Alaskan Seafood Processing Waste Discharges.

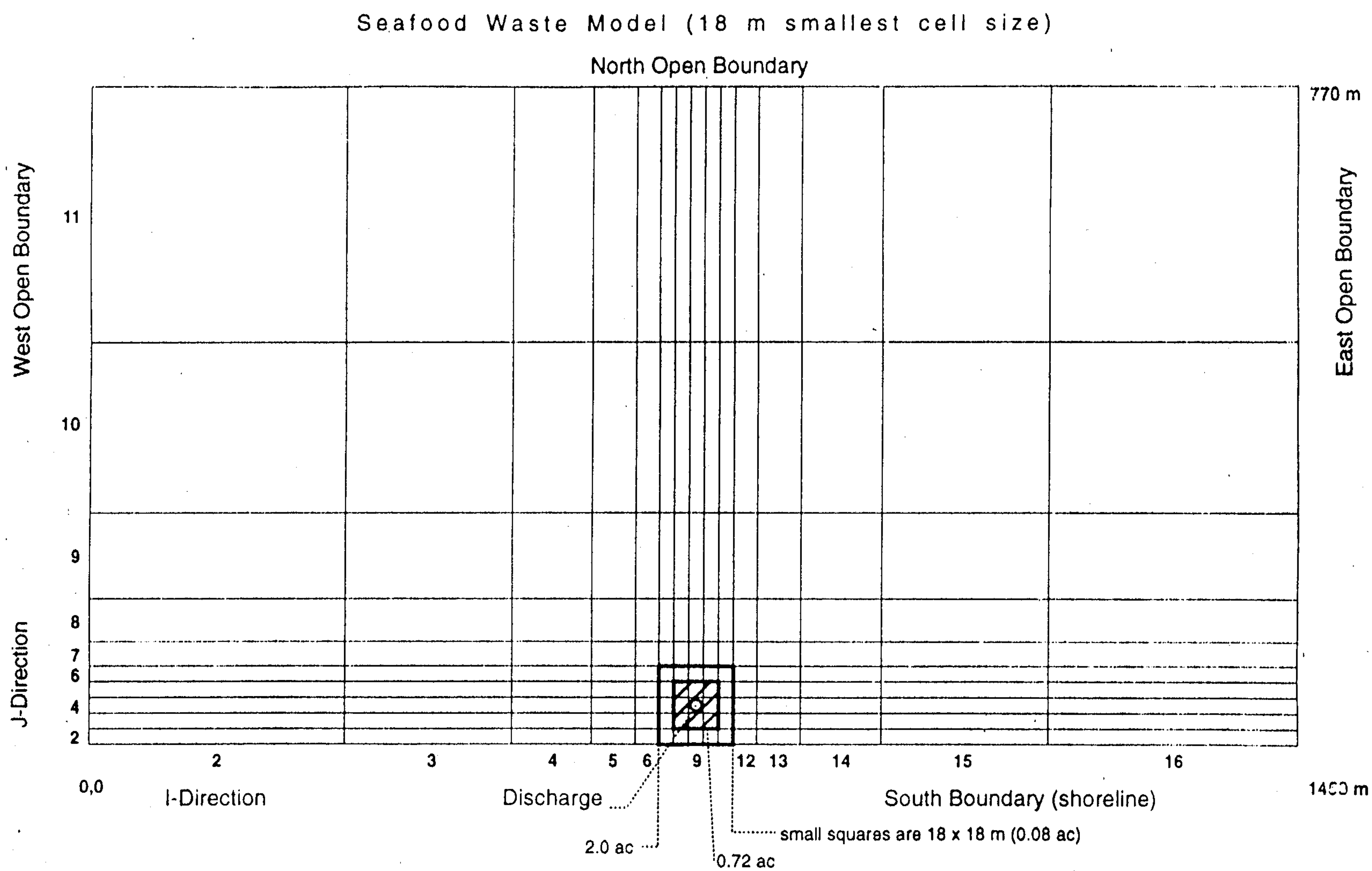

Figure 3-2 Variable-Spaced Model Grid for Shore-Based Seafood Waste Model.

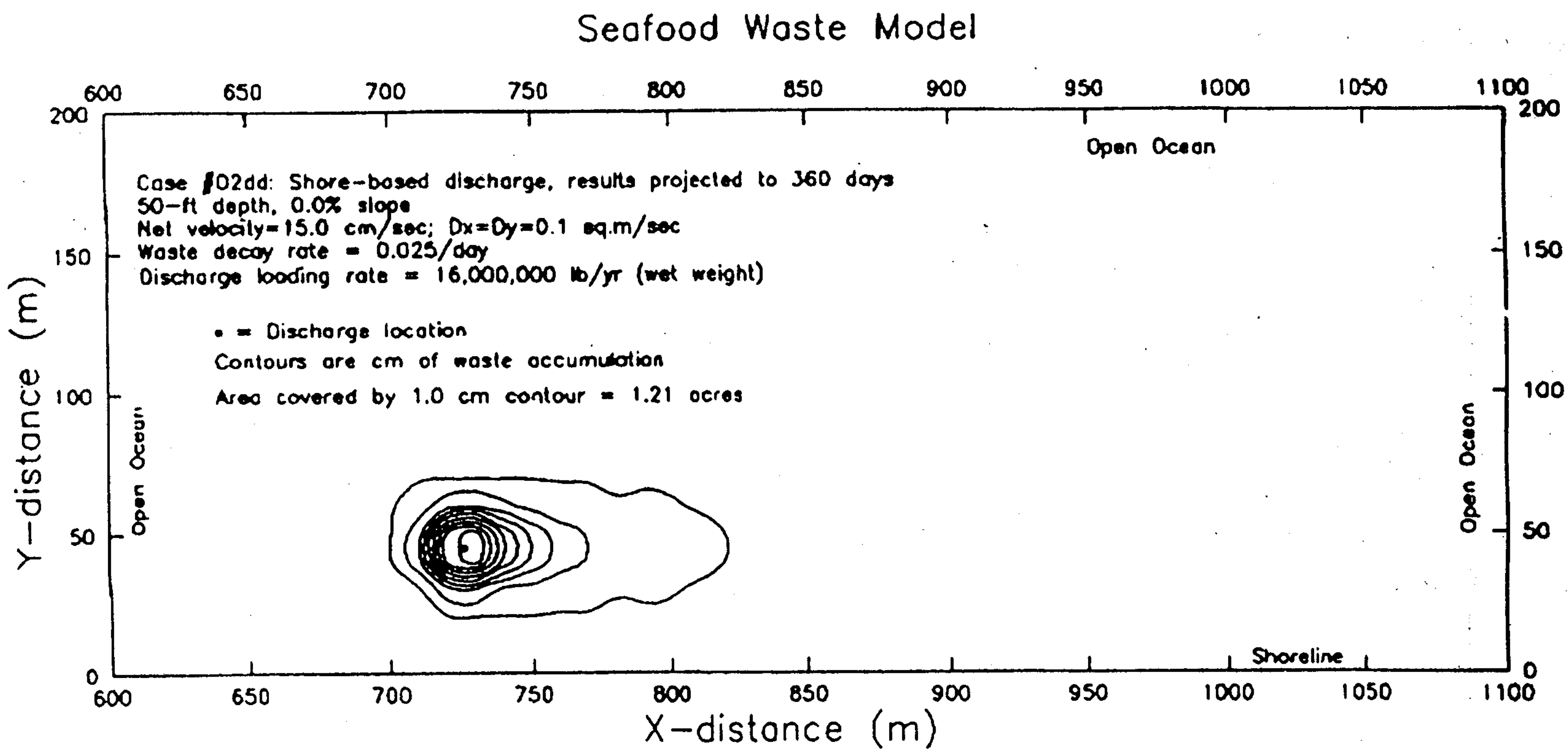

Figure 3-3. Example SURFER™ Contour Plot of Seafood Waste Deposit Depths for a Shore-Based Discharge With a Net-Drift Current Speed of 15 cm/sec, a Decay Rate of 0.025/day, and a Steady Waste Solids Discharge Rate of 16 Million Pounds (wet weight) Per Year.

TABLE 2-10. THEORETICAL COMPOSITION OF SEAFOOD WASTE			
Constituent	Percent Wet Weight	Approximate Density[a] (g/cm^3)	Percent Dry Weight
Water	75	1.0	-
Protein	7	1.5	60
Fat/Carbohydrates	15	0.9	28
Bone/Chitin	3	3.0	12
Total Estimated Wet Weight Density		1.13	
Carbon	16.7[b]	-	50[b]
Nitrogen	2.9[c]	-	8.8[c]
Phosphorus	0.27[c]	-	0.8[c]
Sulfur	0.27[c]	-	0.8[c]

a Typical values in the *Handbook of Chemistry and Physics* (Weast 1982).

b Typical dry weight carbon (C) content of organic matter used.

c Estimated concentrations of nitrogen (N) and phosphorus (P) based on the Redfield ratio of C:N:P (106:16:1 by atoms) in organic matter (Redfield 1958; Redfield et al. 1963). Ratio of sulfur to phosphorus assumed to be 1:1.

TABLE 3-1. SUMMARY OF TIDE RANGES AND MAXIMUM TIDAL CURRENTS AT SELECTED LOCATIONS IN ALASKA

Location	Tide Ranges				Maximum Tidal Currents					
	Mean		Diurnal		Flood			Ebb		
	m	ft	m	ft	m/sec	kn	Degrees	m/sec	kn	Degrees
SOUTHEAST										
Ketchikan	4.0	13.0	4.7	15.4	0.41	0.8	310	0.10	0.2	120
Ward Cove	4.1	13.3	4.8	15.7	-	-	-	-	-	-
Wrangell	4.1	13.3	4.8	15.7	0.41	0.8	050	0.41	0.8	235
Petersburg	4.1	13.4	4.8	15.7	1.9	3.7	225	1.7	3.4	045
Sitka	2.3	7.7	3.0	9.9	0.15	0.3	333	0.21	0.4	156
Juneau	4.2	13.7	5.0	16.3	0.15	0.3	302	0.05	0.1	085
Haines	4.3	14.2	5.1	16.8	-	-	-	-	-	-
Yakutat	2.4	7.8	3.1	10.1	-	-	-	-	-	-
PRINCE WILLIAM SOUND										
Cordova	3.1	10.1	3.8	12.5	0.92	1.8	212	0.51	1.0	0.26
Valdez	3.0	9.7	3.7	12.1	-	-	-	-	-	-
Whittier	3.0	9.8	3.7	12.3	-	-	-	-	-	-
Seward	2.5	8.3	3.2	10.6	-	-	-	-	-	-
COOK INLET										
Seldovia	4.7	15.5	5.5	18.0	-	-	-	-	-	-
Homer	4.8	15.7	5.5	18.1	-	-	-	-	-	-
Kenai	5.3	17.5	6.0	19.8	-	-	-	-	-	-
Anchorage	7.9	25.9	8.8	28.8	1.8	3.5	081	1.6	3.1	234
KODIAK										
Kodiak	2.0	6.6	2.6	8.5	0.46	0.9	056	0.26	0.5	228
Alitak Bay	2.8	9.3	3.6	11.7	-	-	-	-	-	-
Moser Bay	2.8	9.3	3.5	11.6	-	-	-	-	-	-
ALASKA PENINSULA/ALEUTIAN ISLANDS										
Port Moller	2.3	7.6	3.3	10.8	0.46	0.9	158	0.97	1.9	335
Sand Point	1.6	5.2	2.2	7.3	-	-	-	-	-	-
King Cove	1.5	4.8	2.1	6.8	-	-	-	-	-	-
Akutan	0.7	2.4	1.2	3.9	-	-	-	-	-	-
Dutch Harbor	0.7	2.2	1.1	3.7	-	-	-	-	-	-
Atka - Martin H.	-	-	1.0	3.2	-	-	-	-	-	-
Adak - Clam L.	-	-	0.9	2.9	-	-	-	-	-	-
BRISTOL BAY										
Egegik	3.3	10.8	4.1	13.3	-	-	-	-	-	-
Naknek River >Entrance	5.6	18.5	6.9	22.6	-	-	-	-	-	-
>Naknek Air Base	0.6	2.1	1.0	3.2	-	-	-	-	-	-
Dillingham	-	-	-	-	1.7	3.4	030	0.6	2.1	205
PRIBILOFS										
St. Paul	0.6	2.0	1.0	3.2	-	-	-	-	-	-
St. George	-	-	1.0	3.3	-	-	-	-	-	-
St. Matthew Island	0.4	1.3	0.6	2.1	-	-	-	-	-	-
Between St. Paul/St. George	-	-	-	-	0.31	0.6	260	-	-	-
SW Coast - St. Matthew	-	-	-	-	0.62	1.2	292	0.51	1.0	119
ARCTIC-YUKON-KUSKOKWIM										
Nome	0.3	1.0	0.5	1.6	-	-	-	-	-	-
Kotzebue	0.6	2.1	0.8	2.7	-	-	-	-	-	-

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, 1992 Tidal Current and Tide Tables.

TABLE 3-2. ESTIMATED SETTLING VELOCITIES AND CURRENT SPEEDS NECESSARY TO RESUSPEND DIFFERENT SIZES OF SEAFOOD SOLID WASTE PARTICLES					
Seafood Waste Particle Diameter (cm)	Settling Velocity[a] (m/sec)		Resuspension Current Speed[b] (m/sec)		
	$\rho = 1.13$	$\rho = 1.05$	$\rho = 1.05$	$\rho = 1.13$	$\rho = 1.4$
	For a Given Particle Density in g/cm^3				
0.1	0.017	0.0057	0.07	0.11	0.20
0.2	0.036	0.014	0.08	0.15	0.28
0.3	0.055	0.021	0.09	0.18	0.37
0.318 (1/8 in.)	0.058	0.022	0.09	0.19	0.38
0.4	0.072	0.029	0.10	0.22	0.44
0.5	0.089	0.036	0.12	0.25	0.51
0.6	0.105	0.042	0.13	0.28	0.58
0.635 (1/4 in)	0.111	0.045	0.14	0.29	0.60
0.7	0.122	0.049	0.14	0.31	0.64
0.8	0.138	0.055	0.16	0.34	0.70
0.9	0.154	0.062	0.17	0.37	0.76
1.0	0.165	0.068	0.18	0.40	0.82
1.1	0.174	0.075	0.19	0.42	0.86
1.2	0.181	0.081	0.20	0.45	0.90
1.27 (1/2 in)	0.186	0.085	0.21	0.47	0.93
1.3	0.189	0.087	0.22	0.47	0.95

[a] Stokes fall velocity (Sleath 1984). Assumes a seawater density of 1.025 g/cm^3 and a kinematic viscosity of seawater at 5° C equal to 1.52×10^{-6} m^2/sec.

[b] The calculation of the resuspension current speed [i.e., the current speed 1 m (3.3 ft) above the seafloor (U_{100}) that is sufficient to cause resuspension of particles] is based on use of Shield's diagram (Vanoni 1977) to compute the critical shear velocity u_* and the relation $u_* = (0.003)^{.5}\ U_{100}$ (Sternberg 1972).

Conversion Factors:

To convert cm to in multiply cm*0.3937

To convert m/sec to knots multiply m/sec*1.9438

To convert m/sec to ft/sec multiply m/sec*3.2808

TABLE 3-3. IDEALIZED CHEMICAL REACTIONS OF MICROBIALLY MEDIATED ORGANIC MATTER DECOMPOSITION

Microbially Mediated Process:
1. Aerobic respiration $(CH_2O)_x(NH_3)_y(H_3PO_4)_z$[a] $+ (x+2y)O_2 \rightarrow xCO_2 + (x+y)H_2O + yHNO_3 + zH_3PO_4$
2. Nitrate reduction $5(CH_2O)_x(NH_3)_y(H_3PO_4)_z + 4xNO_3^- \rightarrow xCO_2 + 3xH_2O$ $+ xHCO_3^- + 2xN_2 + 5yNH_3 + 5zH_3PO_4$
3. Manganese reduction $(CH_2O)_x(NH_3)_y(H_3PO_4)_z + 2xMnO_2 + 3xCO_2 + xH_2O \rightarrow 4xHCO_3^-$ $2xMn^{2+} + yNH_3 + zH_3PO_4$
4. Iron reduction $(CH_2O)_x(NH_3)_y(H_3PO_4)_z + 4xFe(OH)_3 + 7xCO_2 \rightarrow 8xHCO_3^-$ $+ 3xH_2O + 4xFe^{2+} + yNH_3 + zH_3PO_4$
5. Sulfate reduction $2(CH_2O)_x(NH_3)_y(H_3PO_4)_z + xSO_4^{2-} \rightarrow 2xHCO_3^- + xH_2S + yNH_3 + 2zH_3PO_4$
6. Methane production $2(CH_2O)_x(NH_3)_y(H_3PO_4)_z \rightarrow xCO_2 + xCH_4 + 2yNH_3 + 2zH_3PO_4$
7. Fermentation (generalized) $12(CH_2O)_x(NH_3)_y(H_3PO_4)_z \rightarrow xCH_3CH_2COOH + xCH_3COOH$ $+ 2xCH_3CH_2OH + 3xCO_2 + xH_2 + 12yNH_3 + 12zH_3PO_4$

[a] Theoretical chemical formula for organic matter.

Source: Aller (1982, Table I)

TABLE 3-4. RANGE OF SEDIMENT DECAY RATE CONSTANTS (K) FOR ORGANIC MATERIAL

(day^{-1})	Degraded Substrate	Measurement Method	Location	Reference
1.6×10^{-6} [a]	Refractory organic material	Benthic chamber, core incubation, pore water	Santa Monica Basin, CA	Jahnke 1990
$<8.2 \times 10^{-5}$ [a]	Organic material	^{14}C	Resurrection Bay, AK	Henrichs and Doyle 1986
$>4.1 \times 10^{-4}$ [a]	Labile organic material	Benthic chamber, core incubation, pore water	Santa Monica Basin, CA	Jahnke 1990
1.2×10^{-3} [a]	Organic material	^{14}C	Long Island Sound, NY	Turekian et al. 1980
1.7×10^{-3} - 6.0×10^{-3} [a]	Organic material	Pore water nitrogen	North Sea	Billen 1982
2.3×10^{-3} [b]	Refractory algal material	^{35}S	Long Island Sound, NY	Westrich and Berner 1984
2.7×10^{-3} [b]	Refractory organic material	^{35}S	Long Island Sound, NY	Westrich and Berner 1984
2.7×10^{-3} - 8.2×10^{-3} [a]	Refractory algal material	^{14}C	Resurrection Bay, AK	Henrichs and Doyle 1986
1.0×10^{-2} [c]	--	--	--	EPA 1982
2.0×10^{-2} [b]	Labile organic material	^{35}S	Long Island Sound, NY	Westrich and Berner 1984
2.4×10^{-2} [b]	Labile algal material	^{35}S	Long Island Sound, NY	Westrich and Berner 1984
1.4×10^{-1} [a]	Labile algal material	^{14}C	Resurrection Bay, AK	Henrichs and Doyle 1986
Range: 1.6×10^{-6} - 1.4×10^{-1} day^{-1}				

[a] Total degradation was measured.

[b] Only anoxic degradation was measured.

[c] No experiments were conducted.

TABLE 3-5. SUMMARY OF WASP5 MODELING CASE SCENARIOS OF SHORE-BASED AND OFFSHORE NEAR-SURFACE SEAFOOD SOLID WASTE DISCHARGES					
Case #	Net Velocity (cm/sec)	Total Depth (m)	Surface Layer Thickness (m)	Bottom Layer Thickness (m)	Bottom Slope (%)
Shore-Based Discharges:					
1	5.0	15.24	11.24	4.00	0.0%
2	15.0	15.24	11.24	4.00	0.0%
3	5.0	15.24	11.24	4.00	12.5%
4	15.0	15.24	11.24	4.00	12.5%
5	5.0	15.24	11.24	4.00	25.0%
6	15.0	15.24	11.24	4.00	25.0%
Near-Surface Discharges in Open Ocean:					
7	5.	15.24	2.00	13.24	0.0%
8	15.0	15.24	2.00	13.24	0.0%
9	5.0	30.48	2.00	28.48	0.0%
10	15.0	30.48	2.00	28.48	0.0%
11	5.0	45.72	2.00	43.72	0.0%
12	15.0	45.72	2.00	43.72	0.0%

TABLE 3-6. SEAFOOD WASTE ACCUMULATION MODEL INPUT VARIABLES	
Solids Distribution and Settling Velocities	
Solids Distribution	Settling Velocity (m/sec)
60 percent 20 percent 20 percent	0.085 0.045 0.022
Waste Solids Decay Rate Constant	0.02/day
Lateral and Longitudinal Dispersion Coefficients	$D_x = D_y = 0.1\ m^2/sec$

TABLE 3-7. SEAFOOD WASTE ACCUMULATION MODEL RESULTS							
Case #[a]	Net-Drift Current Speed (cm/sec)	Water Depth (m)	Bottom Slope (%)	Waste Solids Discharge Rate (lb/yr wet weight)	Maximum Waste Accumulation Depth (cm)	Areal Coverage (acres)	
						S[b]	W[c]
Near-Bottom Shore-Based Discharges							
1	5.0	15.2	0.0	16,000,000	230	1.0	0.8
2	15.0	15.2	0.0	12,000,000	133	1.2	1.0
3	5.0	15.2	12.5	20,000,000	230	1.0	0.8
4	15.0	15.2	12.5	16,000,000	179	1.3	1.1
5	5.0	15.2	25.0	20,000,000	288	1.0	0.8
6	15.0	15.2	25.0	16,000,000	179	1.3	1.1
Near-Surface Floating Discharges in Open Ocean							
7	5.0	15.2	0.0	8,000,000	63.4	1.0	0.8
8	15.0	15.2	0.0	4,000,000	19.2	1.2	0.6
9	5.0	30.5	0.0	4,000,000	24.2	1.1	0.9
10	15.0	30.5	0.0	4,000,000	12.3	1.3	1.0
11	5.0	45.7	0.0	4,000,000	18.5	1.2	1.2
12	15.0	45.7	0.0	4,000,000	8.0	1.3	1.0

[a] Case numbers correspond to the case scenarios outlined in Table 3-5.

[b] Areal coverage of solid waste estimated by SURFER™.

[c] Areal coverage of solid waste estimated using WASP output.

1.0 UNALASKA BAY/DUTCH HARBOR TMDL WASTE PILE MODELING

As part of an effort to develop a total maximum daily load (TMDL) for seafood processing wastes discharged to Unalaska Bay/Dutch Harbor and vicinity, the U.S. Environmental Protection Agency (U.S. EPA) requested that Tetra Tech, Inc., evaluate the accumulation and decay of seafood waste piles. The evaluation was performed using the WASP5 model developed as part of the Ocean Discharge Criteria Evaluation (ODCE) for the National Pollution Discharge Elimination System (NPDES) permit for Alaskan seafood processors (Tetra Tech 1994). The WASP5 model simulates the initial settling, accumulation, and microbial decay of seafood solid waste discharged to the marine environment. Two hypothetical discharge scenarios were evaluated; a low and medium current speed case. These scenarios correspond to a steady waste discharge from 2-m (6.6-ft) above a flat bottom in 15.2 m (50 ft) of water. The distribution of the solids in the three particle classes and the particle settling velocities were the same as those used in the Alaskan Seafood ODCE (Tetra Tech 1994). The three particle classes consist of sixty percent solids with diameters of 1.3 cm (0.5 in), twenty percent solids with diameters of 0.635 cm (0.25 in), and twenty percent solids with diameters of 0.318 cm (0.125 in). The settling velocities assigned to these particle classes [0.085 m/sec (0.28 ft/sec), 0.045 m/sec (0.15 ft/sec), and 0.022 m/sec (0.072 ft/sec), respectively] are based on the qualitative observations of Stevens and Haaga (1994). The steady along-shore current speeds used in the model are 5 and 15 cm/sec (0.1 and 0.3 knots) for the low and medium current cases, respectively.

The first-order solids decay rate used in these simulations was based on best professional judgement, as no measurements of the decay of seafood waste solids have been made. A relatively conservative decay rate of 0.002/day was selected which roughly corresponds with the median of the sediment organic matter decay rates found in the literature and summarized in Table 1. The U.S. EPA Technical Support Document for the evaluation of Revised Section 301(h) waiver applications recommends the use of 0.01/day to simulate the accumulation and decay of deposited organic matter discharged from municipal waste treatment facilities. The WASP4 user's manual provides a default value for the benthic organic matter decay rate of 0.0004/day (Ambrose et al. 1988). The value of 0.002/day may be considered a relatively conservative first-approximation of the actual decay rate of the seafood waste solids discharged to Unalaska Bay/Dutch Harbor and vicinity.

The WASP5 seafood waste model was run iteratively to determine, for each of the two case scenarios, the steady seafood waste discharge rate that would result in the accumulation of a one-acre waste pile at steady-state. The one-acre area, or zone-of-deposit, corresponds with the proposed maximum allowable areal bottom coverage of seafood waste for individual facilities covered under the General NPDES permit. The one-acre zone-of-deposit has been proposed by the Alaska Department of Environmental Conservation (ADEC) as a variance to Chapter 70 of the Alaska Administrative Code (18 AAC 70.0). This variance is allowable under the Alaska Administrative Code (18 AAC 70.033) and has been approved by the U.S. EPA.

Following the assessment of the seafood waste solids discharge rate that would result in a one-acre waste pile, the time required for an existing one-acre waste pile to decay microbially following elimination of all seafood waste discharges is determined assuming a decay rate of 0.002/day.

2.0 MODELING RESULTS

For each of the two case scenarios, several model runs were required to identify the steady seafood waste solids mass emission rate that would result in a one-acre waste pile at steady-state (Table 2). For the low current speed case, an annual discharge of 1.5 to 1.9 million pounds (wet weight) of seafood solid waste is predicted to create a one-acre waste pile[1]. The maximum waste accumulation depths that correspond with these discharge rates range from 122 to 154 cm (4.0 to 5.1 ft). For the medium current speed case an annual discharge of 0.6 to 0.7 million pounds (wet weight) is predicted to create a one-acre waste pile. The maximum predicted waste accumulation depths range from 40 to 47 cm (1.3 to 1.5 ft). The top views of these waste piles, based on the highest mass emission rate predicted to create a one-acre waste pile, are shown in Figures 1 and 2.

Using the model results for each of the two case scenarios for the highest mass emission rate predicted to create a one-acre waste pile, a simulation was performed that assumed all seafood waste discharges ceased and that the existing one-acre pile was allowed to decay microbially at a rate of 0.002/day.

The areal coverage and maximum depth of the waste pile 1, 2, 3, 5, and 10 years after termination of seafood processing solid waste discharge are presented in Table 3. For the low current speed case scenario the areal coverage of the wastepile is predicted to decrease to 0.2 acres in 5 years and to a very thin covering of seafood waste (0.1 cm or less) in 10 years. For the medium current speed case the areal coverage of the waste pile is predicted to decrease to 0.1 acres in 5 years, and to a very thin covering of waste (0.03 cm or less) in 10 years.

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[1]The areal coverage and maximum waste accumulation depth estimated by SURFER™ is based on interpolation of the WASP5 model output for the waste accumulation in each modeling grid cell. Because the modeling grid cells become larger farther away from the discharge, the WASP5 results and the SURFER™ results tend to differ more for larger waste piles. Because SURFER™ provides estimates based on smoothed contours that approximate the appearance of an actual waste pile, only SURFER-predicted results are discussed in the text. The areal coverage estimate is based on the area covered by more than 1.0 cm of seafood waste. The conversion between the model input mass emission rate in kg dry wt/day and million pounds wet wt/yr was made assuming that the moisture content of the solid waste is 75 percent.

3.0 REFERENCES

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Tetra Tech. 1994. Draft report. Ocean Discharge Criteria Evaluation for the NPDES General Permit for Alaskan seafood processors. Prepared for U.S. Environmental Protection Agency, Region 10, Seattle, WA. Tetra Tech, Inc., Redmond, WA.

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TABLE 1. RANGE OF SEDIMENT DECAY RATE CONSTANTS (K) FOR ORGANIC MATERIAL

(day^{-1})	Degraded Substrate	Measurement Method	Location	Reference
1.6×10^{-6} [a]	Refractory organic material	Benthic chamber, core incubation, pore water	Santa Monica Basin, CA	Jahnke 1990
$<8.2\times10^{-5}$ [a]	Organic material	^{14}C	Resurrection Bay, AK	Henrichs and Doyle 1986
$>4.1\times10^{-4}$ [a]	Labile organic material	Benthic chamber, core incubation, pore water	Santa Monica Basin, CA	Jahnke 1990
1.2×10^{-3} [a]	Organic material	^{14}C	Long Island Sound, NY	Turekian et al. 1980
1.7×10^{-3} - 6.0×10^{-3} [a]	Organic material	Pore water nitrogen	North Sea	Billen 1982
2.3×10^{-3} [b]	Refractory algal material	^{35}S	Long Island Sound, NY	Westrich and Berner 1984
2.7×10^{-3} [b]	Refractory organic material	^{35}S	Long Island Sound, NY	Westrich and Berner 1984
2.7×10^{-3} - 8.2×10^{-3} [a]	Refractory algal material	^{14}C	Resurrection Bay, AK	Henrichs and Doyle 1986
1.0×10^{-2} [c]	--	--	--	EPA 1982
2.0×10^{-2} [b]	Labile organic material	^{35}S	Long Island Sound, NY	Westrich and Berner 1984
2.4×10^{-2} [b]	Labile algal material	^{35}S	Long Island Sound, NY	Westrich and Berner 1984
1.4×10^{-1} [a]	Labile algal material	^{14}C	Resurrection Bay, AK	Henrichs and Doyle 1986
Range: 1.6×10^{-6} - 1.4×10^{-1} day^{-1}; median = 0.0025/day				

[a] Total degradation was measured.

[b] Only anoxic degradation was measured.

[c] No experiments were conducted.

Case ID	Mass Emission Rate (million wet lbs/yr)	Water Depth (ft)	Decay Rate (per day)	Areal Coverage SURFER (acres)[3]	Areal Coverage WASP5 (acres)[3]	Deposit Depth SURFER (cm)	Deposit Depth WASP (cm)
[1]Low current speed cases							
case001l	0.9	50	0.002	0.8	0.5	73	129
case001m	1.0	50	0.002	0.8	0.6	81	144
case001n	1.1	50	0.002	0.9	0.6	89	158
case001o	1.2	50	0.002	0.9	0.6	97	172
case001p	1.3	50	0.002	0.9	0.8	106	187
case001q	1.4	50	0.002	0.9	0.8	114	201
case001r	1.5	50	0.002	1.0	0.8	122	215
case01a	1.6	50	0.002	1.0	0.8	130	230
case001a	1.7	50	0.002	1.0	0.8	138	244
case001b	1.75	50	0.002	1.0	0.8	142	251
case001c	1.83	50	0.002	1.0	0.8	148	262
case001d	1.9	50	0.002	1.0	0.8	154	273
case001e	2.0	50	0.002	1.1	0.8	161	285
case001f	2.07	50	0.002	1.1	0.8	168	297
case001g	2.15	50	0.002	1.1	0.8	174	308
case001h	2.23	50	0.002	1.1	0.8	181	319
case001i	3.0	50	0.002	1.2	0.9	244	430
case001j	4.0	50	0.002	1.4	0.9	326	576
case001k	5.0	50	0.002	1.5	0.9	405	716
[2]Medium current speed cases							
case002b	0.40	50	0.002	0.8	0.4	27	44
case002c	0.48	50	0.002	0.8	0.4	32	53
case02d	0.5	50	0.002	0.9	0.4	33	56
case002d	0.56	50	0.002	0.9	0.4	37	62
case02e	0.6	50	0.002	1.0	0.4	40	67
case002e	0.7	50	0.002	1.0	0.4	47	78
case02f	0.8	50	0.002	1.1	0.6	53	89
case002f	0.8	50	0.002	1.1	0.6	53	89
case002g	1.0	50	0.002	1.1	1.0	67	112
case002h	1.2	50	0.002	1.2	1.0	80	134
case002i	3.0	50	0.002	1.8	1.2	200	334
case002j	4.0	50	0.002	2.1	1.4	267	445
case002k	5.0	50	0.002	2.2	1.4	333	557

[1]Shore-based discharge, flat bottom, 5 cm/sec alongshore long-term, net-drift current speed.
[2]Shore-based discharge, flat bottom, 15 cm/sec alongshore long-term, net-drift current speed.
[3]Areal coverage of the waste pile greater than 1 cm in depth.

TABLE 3. SIMULATION OF THE LONG-TERM DECREASE IN WASTE PILE SIZE FOLLOWING TERMINATION OF DISCHARGE.

Case ID	Decay Rate	Areal Coverage		Deposit Depth	
		SURFER	WASP5	SURFER	WASP
	(per day)	(acres)[3]		(cm)	
[1]Low current speed case - 1.9 million pounds (wet wt) per year					
Year					
1	0.002	0.8	0.5	74	132
2	0.002	0.7	0.5	36	63
3	0.002	0.5	0.2	17	31
5	0.002	0.2	0.2	4	7
10	0.002	0	0	0.1	0.2
[2]Medium current speed case - 0.7 million pounds (wet wt) per year					
Year					
1	0.002	0.7	0.4	23	38
2	0.002	0.5	0.2	11	18
3	0.002	0.3	0.2	5	9
5	0.002	0.1	0.1	1	2
10	0.002	0.0	0.0	0.03	0.05

[1]Shore-based discharge, flat bottom, 5 cm/sec alongshore long-term, net-drift current speed.
[2]Shore-based discharge, flat bottom, 15 cm/sec alongshore long-term, net-drift current speed.
[3]Areal coverage of the waste pile greater than 1 cm in depth.

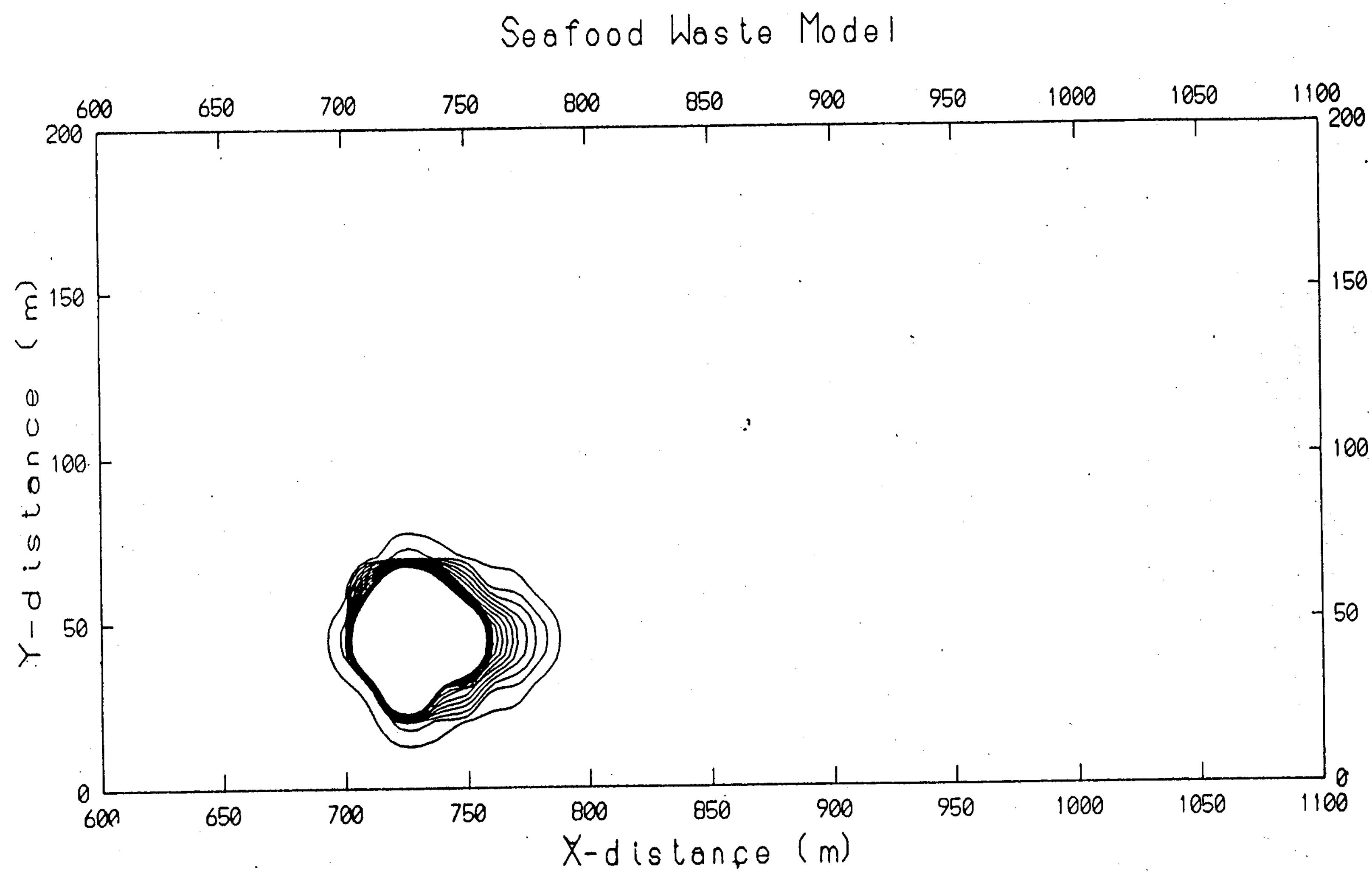

Figure 1. Top View of a 1-Acre Seafood Waste Pile Created by a Steady Shore-Based Discharge of 1.9 Million Pounds (wet weight) Per Year to Waters With a Steady Along-Shore Current of 5 cm/sec (0.1 Knots).

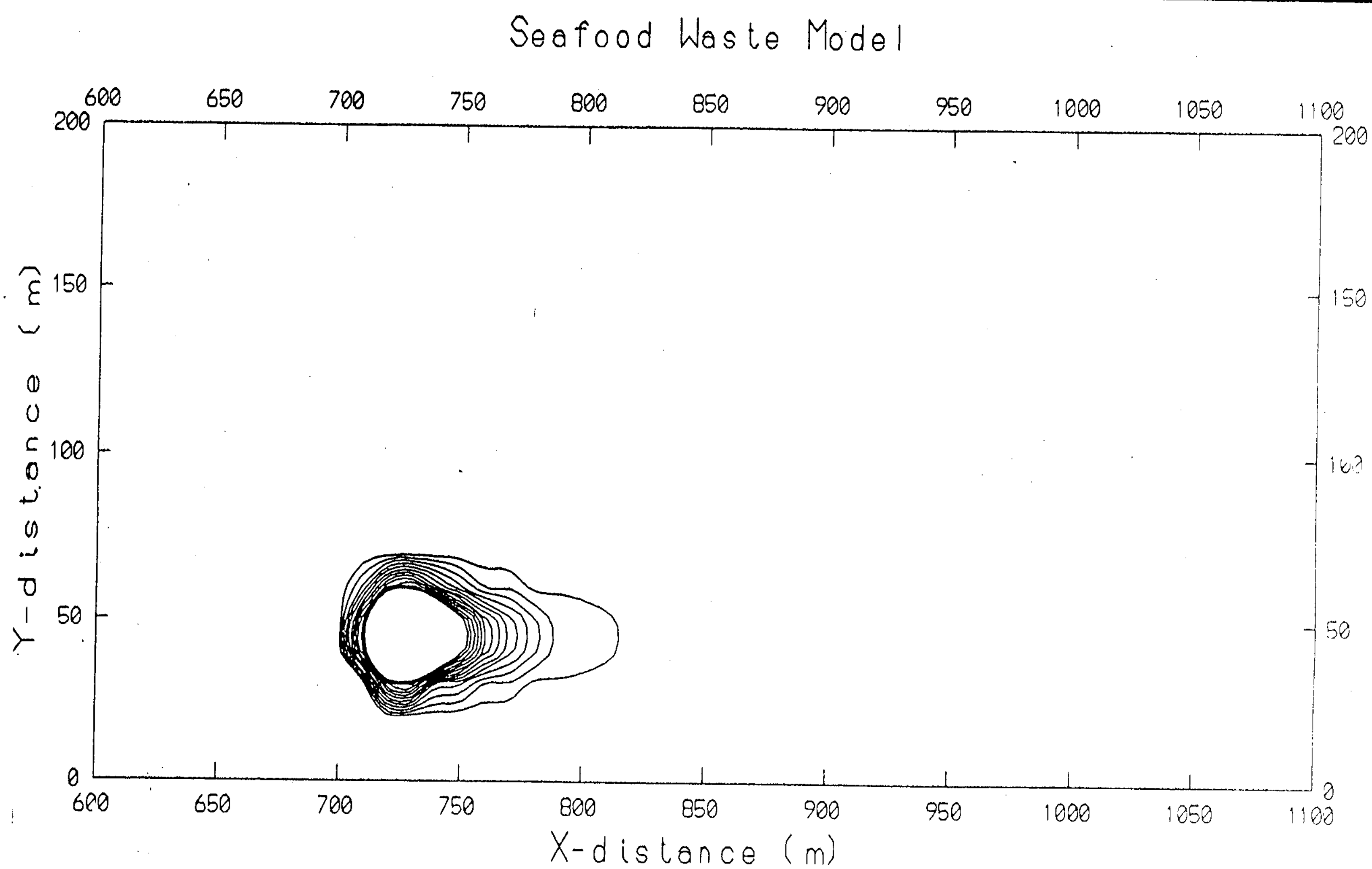

Figure 2. Top View of a 1-Acre Seafood Waste Pile Created by a Steady Shore-Based Discharge of 0.7 Million Pounds (wet weight) Per Year to Waters With a Steady Along-Shore Current of 15 cm/sec (0.3 Knots).